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14. ABSTRACT

The overall goal of this DURIP project is to acquire major facilities that are critical in the development of a comprehensive experimental testbed for advancing the technology of low vibration *periodic structures* (e.g., bladed-disk assemblies and satellite antennae). Some of the main hardware components include a laser vibrometer system, an isolation table, high-performance mid-range travel linear stages and motion controller, and a 6-channel power amplifier. The proposed new equipment will directly enhance the Principal Investigator's current AFOSR research program (Grant number F49620-01-1-0156). The research results will be useful for many Air Force applications, such as in space structures and jet engine fan/turbine blade structures (conclusion based on technical discussions with Wright-Patterson and Kirtland Air Force Research Labs).

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Research Instrumentation for Investigating Vibration Delocalization and Control of Nearly Periodic Structures via Piezoelectric Networks

GRANT F49620-02-1-0350 (DURIP)

Final Report

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OBJECTIVE

The overall goal of this DURIP project is to acquire major facilities that are critical in the development of a comprehensive experimental testbed for advancing the technology of low vibration *periodic structures* (e.g., bladed-disk assemblies and satellite antennae). The proposed new equipment will directly enhance the Principal Investigator's current AFOSR research program (Grant number F49620-01-1-0156). The results will be useful for many Air Force applications, such as in space structures and jet engine fan/turbine blade structures (conclusion based on technical discussions with Wright-Patterson and Kirtland Air Force Research Labs).

DESCRIPTION OF NEW FACILITIES

The major facilities purchased and developed using the DURIP grant are described in the following paragraphs.

(a) Laser Vibrometer (Polytec PI)

The purpose of the Laser Vibrometer system is to perform non-intrusive and accurate measurement of the bladed-disk (blisk) assembly structural vibration response. The system includes a laser sensor head (Tripod mountable laser sensor head with motorized lens for remote focus. Stand-off distance > 230 mm.), remote focus handset, a scanning vibrometer controller

(Vibrometer controller with multiple range velocity decoder; low-pass filter with multiple cut-off frequencies; bandwidth 250 kHz (-3 dB) with filter off; minimum velocity resolution < 0.25 $\mu m/s$), and a displacement output decoder. (Figures 1, 2 and 3)

(b) RS3000 Isolation Table (Newport Corporation)

To ensure that the vibration measurement and control experiments are performed in a "clean" environment, the fixtures and instruments are mounted on this vibration isolation table (Figures 1 and 4) with the following characteristics: 3 foot $\times$ 6 foot $\times$ 8 inch, tuned internal table top damping, guaranteed Maximum Dynamic Deflection Coefficient $< 0.85\times10^{-3}$ (PSD 10^{-9}/transmissibility 0.01), and guaranteed Maximum Relative Motion Value $< 6.6\times10^{-9}$ inch.

(c) IMS500CC High-Performance Mid-Range Travel Linear Stages and ESP6000-SYS-2 Two-Channel Motion Controller (Newport Corporation)

For vibration measurement, the laser sensor head is mounted on these linear stages, which can control the position/motion of the measurement with high precision. The stages feature robust designs with high performance. It provides linear travel range of 500mm in both horizontal and vertical directions. A highly-stiff, backlash-free, 5 mm pitch ball screw ensures rapid movements with fast step and settling times. Position measurements are read on a 4000 pts/rev. rotary encoder. For optimum performance and seamless compatibility, ESP6000-SYS-2 Two-Channel Motion Controller/Driver is used to control the two linear stages. (Figures 1, 2 and 5)

(d) 790A60 6-channel Power Amplifier (PCB Piezotronics, Inc.)

The 790A60 6-channel Power Amplifier is designed to drive the piezoelectric actuators for high precision, wide bandwidth applications such as active vibration controls. The peak voltage is 200 V. The peak output current is 50 MA. Voltage gain is 5-50 adjustable. Maximum capacitive loading is 100-1000 nf. Signal Bandwidth (-3dB) is 50-5 kHz. (Figure 6)

(e) Integrated Testbed

Through utilizing the equipment described above and rest of the DURIP grant from AFOSR, a comprehensive test stand has been set up (Figure 1) and preliminary measurements have been

obtained. Through working with the Wright Patterson Air Force Lab, an eighteen blade, one-foot diameter test blisk (bladed-disk) specimen has been selected and fabricated. The test structure is excited using an electro-magnetic shaker mounted to the hub of the blisk and/or piezoelectric patches on the blades. The vibration signals are measured using the laser vibrometer mentioned above. Without treatment, the localization phenomenon was clearly observed, as some of the blades have much higher amplitudes than others under a forced resonant excitation scenario (Figure 7). To experimentally realize the negative capacitance concept (an electromechanical coupling enhancement concept developed in the current AFOSR research program), an OP amp based negative impedance converter circuit is developed and integrated with the piezoelectric patch-blade structure. Through measuring the frequency response function, one can estimate the electromechanical coupling coefficient ξ. In the given experiment, it is observed that ξ can be easily increased from 0.1224 to 0.3416 with the negative capacitance circuit. It is expected that with further improvement of the circuitry, one can further increase the coupling and hence reduce the system vibration localization.

ENHANCEMENT OF CURRENT RESEARCH PROGRAM WITH DURIP

The results obtained from the current AFOSR supported research project at Penn State (Grant number F49620-01-1-0156) have been promising. However, the scope of the present research program was limited to analytical efforts and small-scale experiments (mostly free vibration or impact tests). To quantitatively validate our analysis predictions and verify the potential of using such technology in the aforementioned Air Force applications, more precise measurements and larger scale closed-loop control experiments under forcing conditions need to be conducted. Due to the high-modal density and uncertainty-sensitive (system dynamics could change drastically with small changes in the system parameters) nature of the localization problem, the measurement devices (sensors) need to be non-intrusive (have minimum effect on the original structural dynamics) and with high accuracy. This DURIP grant has provided us with such an opportunity and greatly enhanced the present program.

The equipment and testbed developed under this DURIP program have been and will continue be used to

- Experimentally evaluate the different piezoelectric network architectures and control schemes developed in the current AFOSR supported research program.
- Provide precise and non-intrusive measurements for evaluating the nearly periodic structural response and delocalization effect.
- Provide validations of utilizing the piezoelectric network control for simultaneous delocalization and vibration control of nearly-periodic structure under various forcing scenarios (e.g., engine order excitation in turbo machinery).
- Train graduate students with thesis topics in the areas of structural vibration controls and smart structures (hands-on ability).

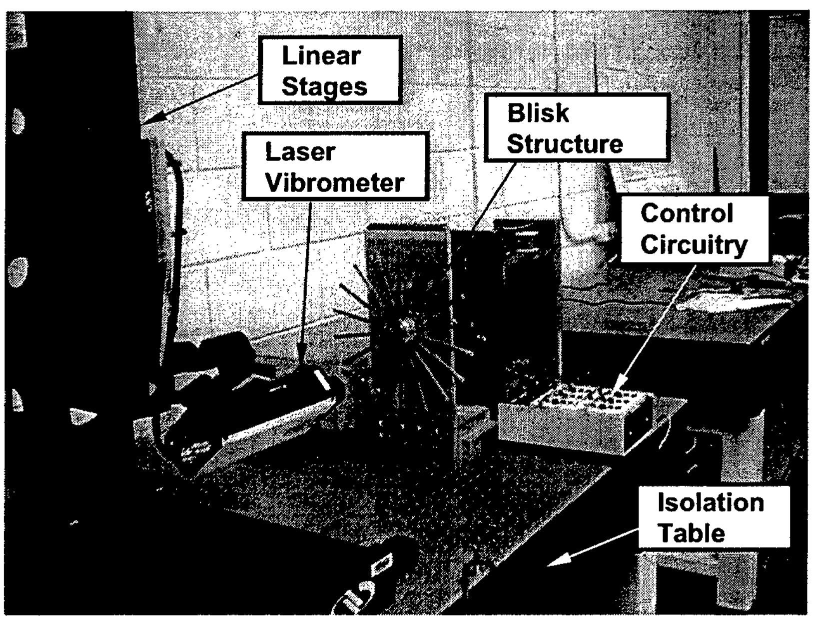

Figure 1. Integrated testbed setup

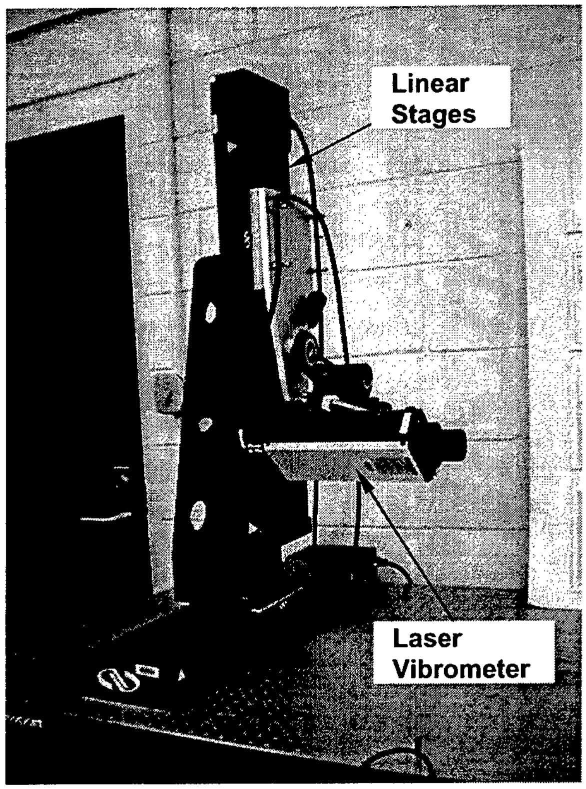

Figure 2. Laser vibrometer and linear stages

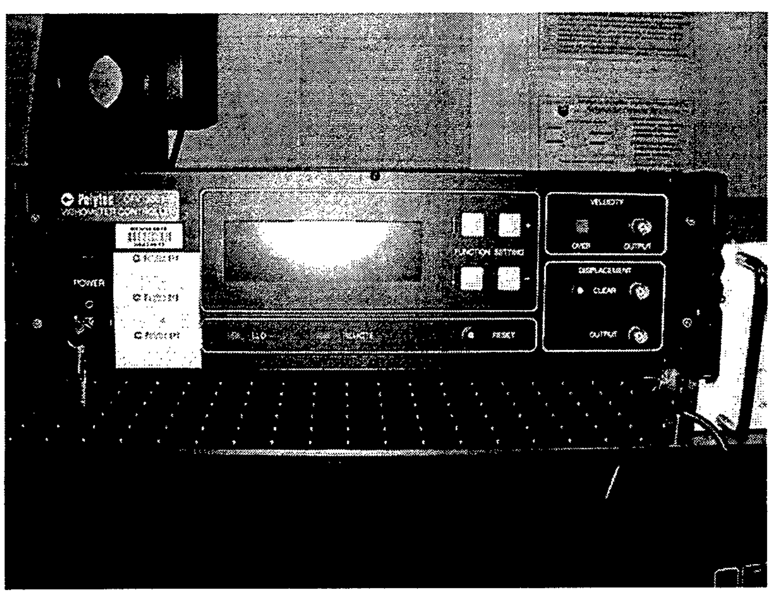

Figure 3. Laser vibrometer controller

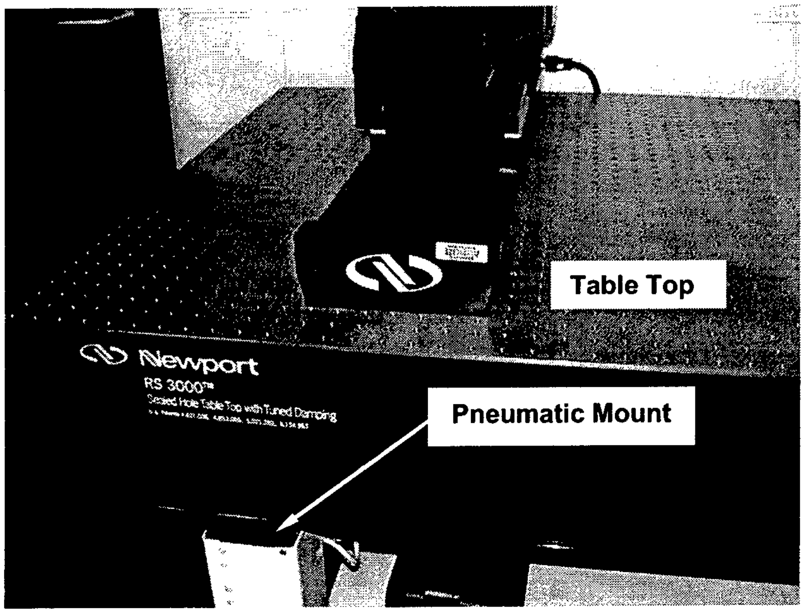

Figure 4. Isolation table

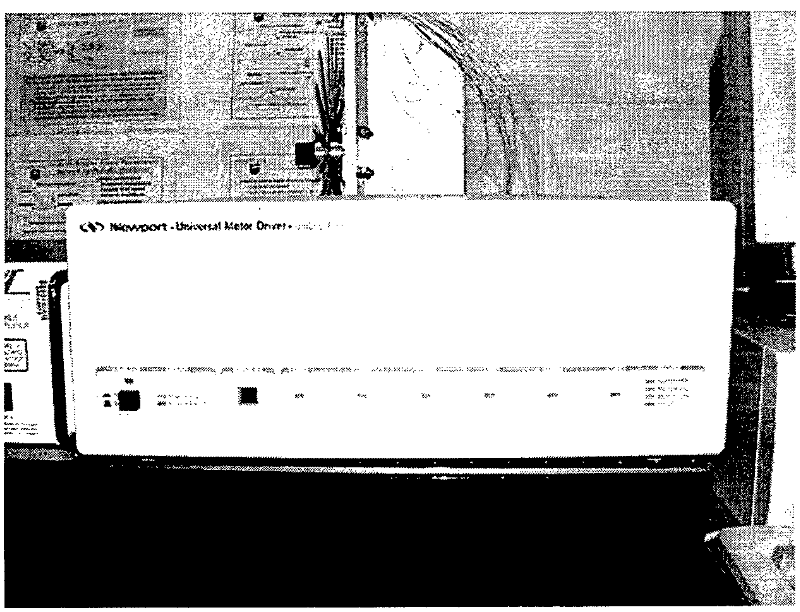

Figure 5. Linear stage motion controller

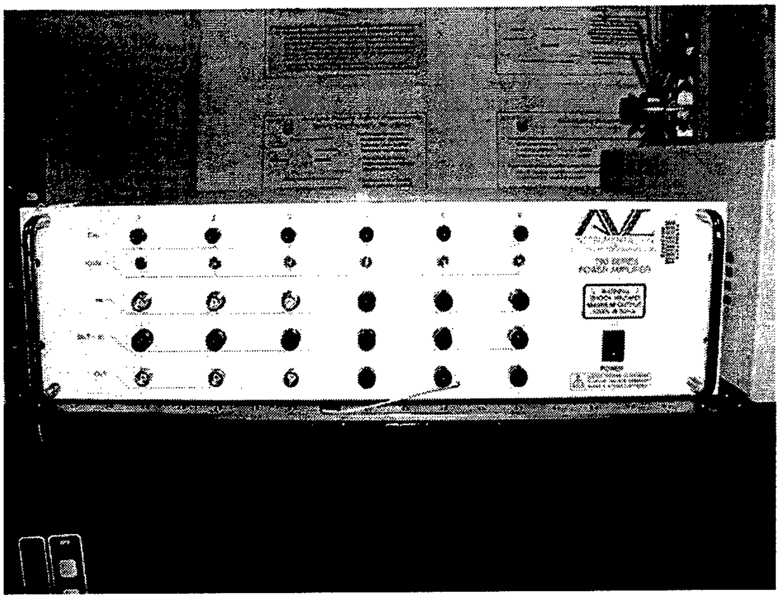

Figure 6. Six channel power amplifier

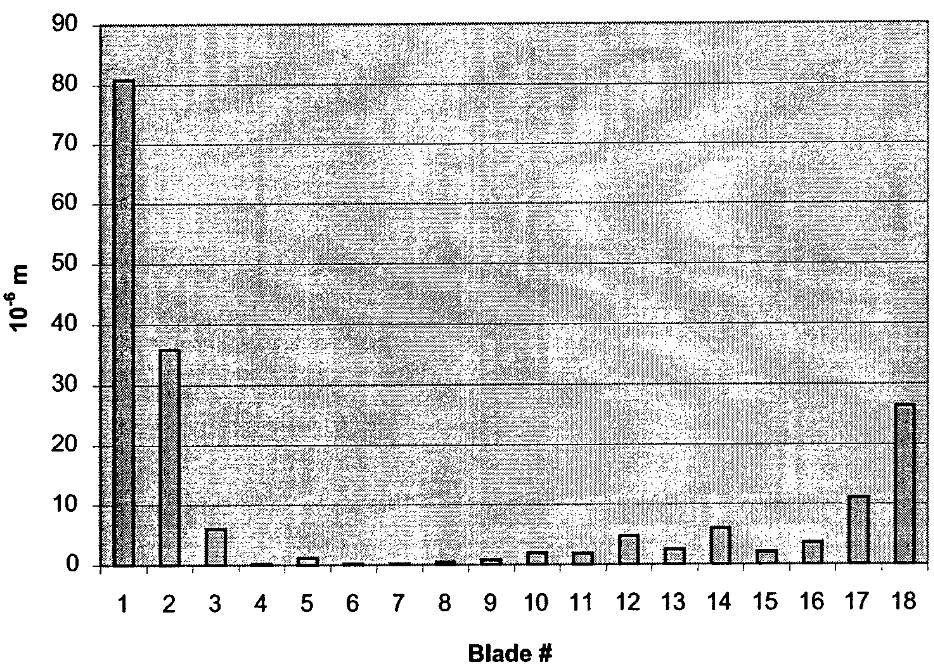

Figure 7. Test results showing blade vibration amplitudes under resonant excitation of system without treatment